COMPARISON OF EROSION CORROSION OF TITANIUM AND STAINLESS STEEL IN SEAWATER

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ABSTRACT

The application of Stainless steel and Titanium alloy had been rising in marine application that promoted this study to investigate erosion corrosion behaviour for Stainless steel grade 301 and Titanium. Erosion corrosion test were conducted for both material at constant rate velocity, 900 rpm and at ambient temperature in the range 27^{o}C-30^{o}C. The erosion corrosion were carried out by immersing specimens in an aqueous 3.5%NaCl and presence of 10 wt % sand particles. The erosion corrosion tests were done by using electrochemical test which involve oxidation and reduction process. Graphite is use as counter electrode while specimens as working electrode and saturated calomel electrode (SCE) as reference electrode. Potentiodynamic polarization has been carried out by using potentiostat model WPG100i with potential scan rate use is 20 mVs^{-1} and potential range of -0.8V until 0.2V. Analysis of image and surface roughness, were taken before and after erosion corrosion test. Titanium alloy show small pitting form and low value of surface roughness compare to Stainless steel. The full observation on the result from the test shows that corrosion rate of Stainless steel is higher than the corrosion rate for Titanium alloy.

ABSTRAK

Aplikasi keluli tahan karat dan Titanium aloi dalam industri marin semakin mendapat perhatian dan meningkat.Tesis ini mengkaji hakisan karatan akibat pergerakan bendalir yang mempercepatkan pengaratan dari permukaan logam.Ujian untuk proses pengaratan yang melibatkan pergerakan dijalankan dengan menggunakan halaju yang tetap iaitu 900 rpm dengan suhu sekeliling pada suhu bilik iaitu 27^{o}C-30^{o}C.Ujian dijalankan dengan merendam spesimen di dalam larutan akueus 3.5%NaCl dengan kehadiran 10% pasir pantai daripada larutan akueus.Analisis dilakukan dengan menggunakan ujian elektrokimia yang melibatkan proses pengoksidaan dan penurunan.Grafit digunakan sebagai 'counter electrode' ,specimen pula sebagai elektrod yang mengalami proses penurunan manakala 'saturated calomel electrode'(SCE) sebagai elektrod rujukan. Pembelauan dengan menggunakan alat WPG100 potentiostat menggunakan kadar imbasan 20mVs^{-1} dan skala voltan ialah -0.8V hingga 0.2V.Analisis kesan daripada pengaratan dan impak yang terhasil daripada pelanggaran pasir ke atas specimen mendapati kadar pengaratan Titanium aloi lebih kurang berbanding dengan keluli tahan karat yang menunjukkan kadar pengaratan lebih tinggi.

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LIST OF SYMBOLS

mdd	Mg/ dm2/day
ipy	Inch penetration/ year
mpy	Mils penetration/year
W	Weight loss (mg)
D	Density of metal (g/cm3)
A	Area of specimen ($in.^2$)
CO_2	Carbon dioxide
H_2S	Hydrogen sulphide
ϕ	Diameter
N	Newton

LIST OF ABBREVIATIONS

Ti	Titanium
SS	Stainless steel
Cr	Chromium
Zn	Zinc
SCC	Stress Corrosion Cracking
NaCl	Natrium Chloride
CF	Corrosion fatigue
Ni	Nickel
Cu	Copper
Mo	Molybdenum
Ta	Tantalum
Zr	Zirconium
EEC	Erosion-enhanced corrosion
CAE	Corrosion-affected erosion
Wt	Weight
CP	Cathodic protection
SCE	Saturated calomel electrode
HRC	Hardness Rockwell C

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Most commonly used metals are unstable in the atmosphere. These unstable metals are produced by reducing ores artificially, and therefore they tend to return to their original state or to similar metallic compounds when exposed to the atmosphere. Exceptions to this are gold and platinum, which are already in their metal state. Corrosion by its simplest definition is the process of a metal returning to the material's thermodynamic state. For most materials, this means the formation of the oxides or sulphides from which they originally started when they were taken from the earth before being refined into useful engineering materials.

These changes are electrochemical reactions that follow the laws of thermodynamics. Understanding the interactions of materials with their environment now takes on the added dimension of chemistry and electricity. These concepts help explain why corrosion processes are time and temperature dependent. They also establish that the corrosion reactions, or rates, are affected by ion and corrodent concentrations, and explain why some reactions are reversible or controllable while others are not. Corrosion in aqueous solutions is the most common of all corrosion processes.

Water, seawater, and various process streams in industry provide an aqueous medium. Moisture in the atmosphere and water in the soil account for the aqueous corrosion in these media. In all these cases, water is seldom present in pure form. Rather, various salts and gases remain dissolved in it, and their dissociation renders

the water somewhat conducting. For all practical purposes, it acts as an electrolyte. The chemical nature of this electrolyte may be acidic, alkaline, or neutral.

Erosion-corrosion is one of tribocorrosion process which includes abrasion-corrosion and cavitation-corrosion for examples. These are not specific form of corrosion but are degradation processes which involve the action of a mechanical process in conjunction with electrochemical corrosion process. The importance of erosion-corrosion in term of cost incurred by industry due to premature material failures. Erosion-corrosion was ranked as the fifth most important degradation mechanism in offshore and chemical sectors.

Erosion-corrosion is associated with a flow-induced mechanical removal of the protective surface film that results in a subsequent corrosion rate increase via either electrochemical or chemical processes. It is often accepted that a critical fluid velocity must be exceeded for a given material. The mechanical damage by the impacting fluid imposes disruptive shear stresses or pressure variations on the material surface and/or the protective surface film. Erosion-corrosion may be enhanced by particles (solids or gas bubbles) and impacted by multi-phase flows. The morphology of surfaces affected by erosion-corrosion may be in the form of shallow pits or horseshoes or other local phenomena related to the flow direction.

1.2 PROBLEM STATEMENT

Study of erosion-corrosion due to failure in marine application such as shaft, propeller and piping because of impingement of sand particles on metals.

1.3 OBJECTIVES OF PROJECT

i. To study the effect of different material to erosion-corrosion behaviour
ii. To study the erosion corrosion impact to material in aqueous slurries

1.4 SCOPES OF PROJECT

i. Comparison of Titanium and Stainless steel
ii. Constant velocity
iii. Investigation of surface roughness change
iv. Surface image analysis using image analyzer

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Corrosion stands for deterioration or damage to material or metal surfaces in an aggressive environment. Corrosion is a chemical or electrochemical oxidation process, in which electron transfer to the environment and lead valence changes from zero to positive values. The environment can be liquid, gas or hybrid-liquefied soil. This environment is called an electrolyte because they have their conductivity for electron transfer.

Corrosion also defines as term of attack on a metallic material by reaction with its environment. The concept of corrosion not only limited to the metallic materials, but also attack on non-metallic materials. But, in this study, we will focus on metallic material corrosion. Corrosion of metallic materials can be divided into three main groups (Metals Handbook, 1987):

1. Wet corrosion, where the corrosive environment is water with dissolved species. The liquid is an electrolyte and the process is typically electrochemical.
2. Corrosion in other fluids such as fused salts and molten metals.
3. Dry corrosion, where the corrosive environment is a dry gas. Dry corrosion is also frequently called chemical corrosion and the best-known example is high temperature corrosion.

2.1.1 Wet corrosion

Wet corrosion is corrosion that cause by exposure of material to aqueous solution. The mechanism of wet corrosion is show in Figure 2.1.

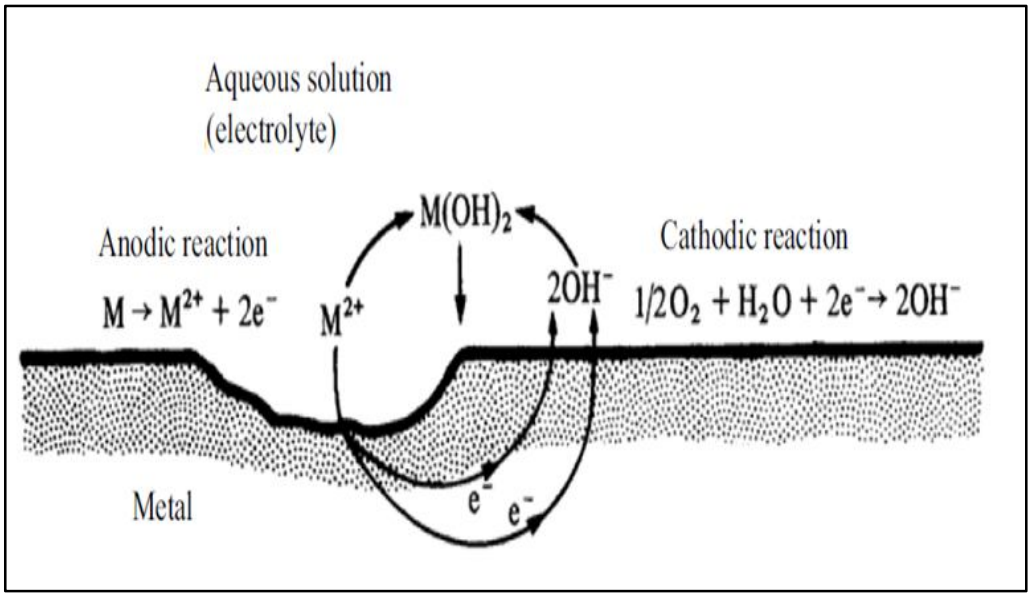

Figure 2.1: Wet corrosion of a divalent metal M in an electrolyte containing oxygen

Source: Einar Bardal (2003)

The dissolution process in Figure 2.1 is known as wet corrosion and electrochemical mechanisms normally. In electrochemistry aspects, corrosion process consists of anodic and cathode reactions. In the anodic reaction (oxidation), the metal dissolved and transferred to the solution as M^{2+} ions. The reaction of oxygen reduction in cathode is example. It is seen that the process of making electrical circuits without the collection of any charges. Electrons that produced from anodic reaction are carried out through the metal to the cathode where they are involved in the cathode reaction. The conditions necessary for the process of corrosion is that the environment is fluid running (electrolytes) that is in contact with metal. Electrical circuit is closed by the flow of ions through the electrolyte (Einar Bardal, 2003).

2.2 TYPE OF CORROSION

Although there is only one basic mechanism of corrosion, electrochemical cell, there are certain types of rust or corrosion that can occur. Each attack has a certain order form anodes and cathode and the erosion that occurs with a specific location and pattern. The types of the most important corrosion (Einar Bardal, 2003):

1. Uniform (general) corrosion
2. Galvanic (two–metal) corrosion
3. Thermogalvanic corrosion
4. Crevice corrosion (including deposit corrosion)
5. Pitting corrosion
6. Intergranular corrosion (including exfoliation)
7. Erosion and abrasion corrosion
8. Cavitation corrosion
9. Fretting corrosion
10. Stress corrosion cracking
11. Corrosion fatigue

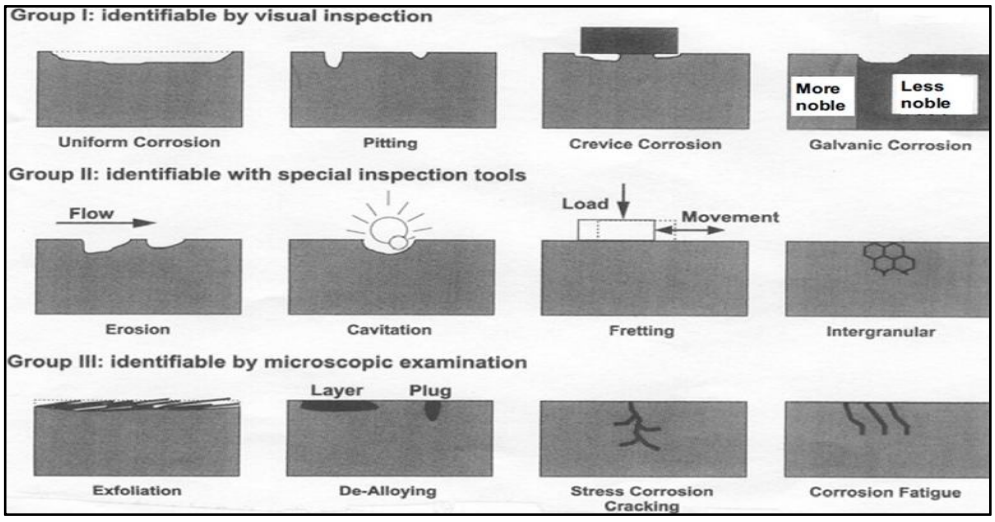

Figure 2.2: Main forms of corrosion grouped by their ease of recognition

Source: Roberge PR (1977)

Figure 2.3 shows that data collect for corrosion occur done by Japan oil refineries and petrochemical industries. More than 80% of material failure due to corrosion (wet and dry). The high proportion of stress corrosion cracking/corrosion fatigue is particularly noticed.

Corrosion failures	%
General corrosion	31.5
Stress corrosion cracking Corrosion fatigue	23.4
Pitting corrosion	15.7
Intergranular corrosion	10.2
Corrosion–erosion Cavitation damage Fretting corrosion	9.0
High–temperature corrosion	2.3
Weld corrosion	2.3
Thermogalvanic corrosion	2.3
Crevice corrosion	1.8
Selective attack	1.1
Hydrogen damage	0.5
Galvanic corrosion	0.0

Figure 2.3: Material failures over a two-year period (56.9 % corrosion and 43.1% mechanical)

Source: Pludek VR. (1977)

2.2.1 Uniform (general) corrosion

Type of corrosion which attack on material surface distributed uniformly over the surface. This process will lead to relatively uniform thickness reduction of surface that open to reaction (Nestor Perez, 2004).

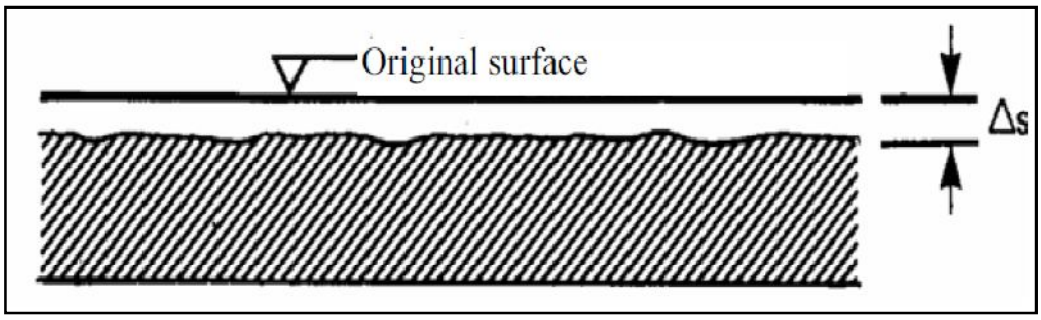

Figure 2.4: Uniform (general) corrosion

Source: Einar Bardal (2003)

Uniform corrosion is assumed to be the most common form of corrosion and particularly responsible for most of the material loss. Traditionally, however, it is not recognized as a dangerous form of corrosion, because:

1. Prediction of thickness reduction rate can be done by means of simple tests.
2. Corrosion allowance can be added, taking into account strength requirements and lifetime.

2.2.2 Galvanic corrosion

Galvanic corrosion of either chemical or electrochemical corrosion .This is due to the potential difference between two different metals connected through the circuit for current flow occurs from the more active metal (more negative potential) to the more noble metal (the more positive potential). There also must have an electrolytic connection between the metals so that close circuit is established (Nestor Perez, 2004).

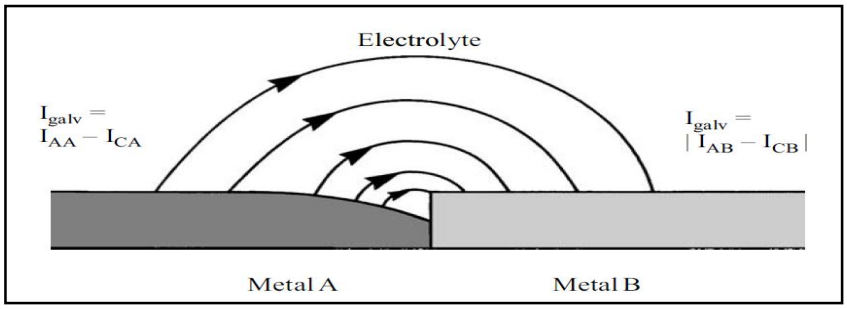

Figure 2.5: Galvanic corrosion

Source: Einar Bardal (2003)

Figure 2.5 show the mechanism of galvanic corrosion. The closer the standard potentials of two metals the weaker the galvanic effect and vice versa.

2.2.3 Thermogalvanic corrosion

When the material in a corrosive environment subject to temperature gradients, galvanic element may arise, causing what we call thermo-galvanic corrosion. Typically, the hot surface is form the anode and a cold is cathode (Figure 2.6).This is because the anodic properties of the material depend on temperature. In addition, the characteristics of the environment along the surface of the metal will also vary due to different temperatures and different temperature gradients normal to metal surfaces. This often affects the cathode reaction, which also must be taken about the corrosion of analysis (Einar Bardal, 2003).

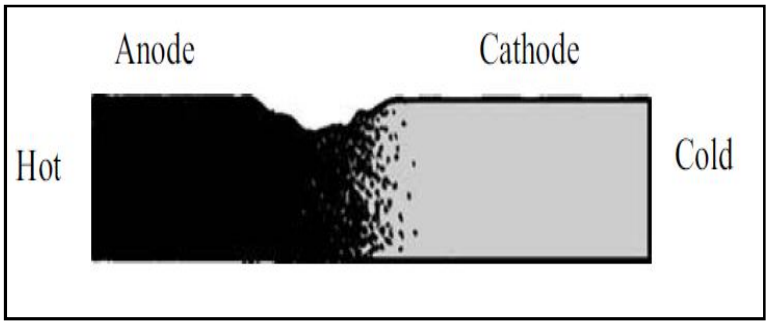

Figure 2.6: Thermogalvanic corrosion

Source: Einar Bardal (2003)

2.2.4 Crevice corrosion

This is a localized corrosion which concentrated at gap that big enough for the liquid to penetrate cracks and narrow enough for the liquid to be stagnant. For example, given the conditions under which corrosion occurs at flange gaskets, nail and screw head and the edge of the paint coating and many other examples can be studied for this type of corrosion.

Typical crevice corrosion occur between the passive material before hand, or materials that can be easily passivated such as stainless steel, aluminium, unalloyed or low alloy steels in a more or less alkaline, the material is exposed to an aggressive species such as chloride can lead to local breakdown of surface oxide layer. Materials such as stainless steel can be a lot of conventional attack by corrosion deposits in stagnant waters or slow flowing. The critical velocity of about 2 m / s has been assumed, but corrosion cracks can also occur at high velocity. The most common form of corrosion observed in environments containing chloride, but can also occur in other salt solutions (Ijsseling, 1979–1998).

The mechanism of crevice corrosion is electrochemical in nature and illustrated in Figure 2.7. It requires a prolong time to start the metal oxidation process, but it may be accelerated afterwards.

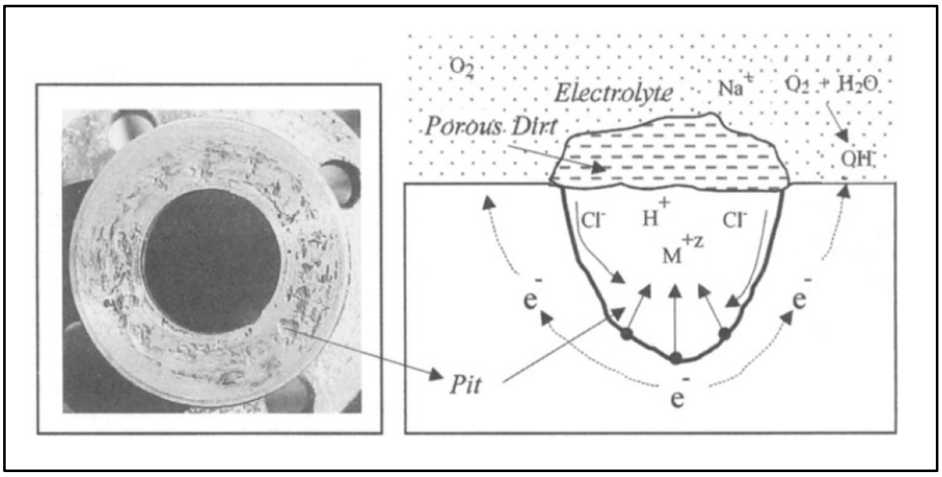

Figure 2.7: Crevice corrosion. a) Stainless steel flange b) mechanisms

Source: M.G. Fontana (1986)

2.2.5 Pitting corrosion

Pitting corrosion occurs on more or less passivated metal and alloys in environment containing chloride, bromide, iodide or pechlorate ion when electrode potential exceed a critical value, the pitting potential, which depend on various condition.

This form of corrosion is characterized by narrow pits with a radius of the same order of magnitude as, or less than, the depth. The pits may be of different shape, but a common feature is the sharp boundary as shown in Figure 2.8. Pitting is a dangerous form of corrosion since the material in many cases may be penetrated without a clear warning (because the pits often are narrow and covered) and the pit growth is difficult to predict. This is connected to the fact that the extent and the intensity of pitting corrosion are difficult to measure because the number and size of pits (diameter and depth) vary from region to region and within each region (Einar Bardal, 2003).